<u>Project</u>: Service Oriented Enterprise Architecture for Manufacturing

1. PROJECT SUMMARY

The scope of the SoEA4M project is to conceive, design, implement and test a generic Manufacturing Execution System (MES), realized as a functional model, capable of controlling job shop-type manufacturing structures (flexible cells and systems) in both centralized, hierarchical- and decentralized, heterarchical modes in order to ensure *global optimization* on largest possible time horizons and *agility to changes* in customer orders, while featuring *robustness to disturbances* in the production environment.

The design is based on developing first a self-organizing, reconfigurable control model for job-shop type manufacturing with automatic, event- and decision-driven commuting between centralized, hierarchical mixed batch planning and scheduling (*Scheduling System* - SS) and decentralized, heterarchical operation scheduling and resource allocation (*distributed MES* - dMES) for individual product execution.

The control architecture uses distributed intelligence in hybrid computing topology, being able to self-reconfigure its structure, components and operating modes at changes in production orders, resource breakdowns and performance degradation. The MES will also allow risk and hazard control by predicting unexpected situations and atypical work conditions.

Secondary performance objectives are: MES nervousness, schedule stability, smooth plant operation, level of centralized (SS) guidance, flexibility and adaptability of the coupled system MES + shop-floor to material flow and working environment variations. Service orientation is imposed as a behavioural mode to estimate the current resource status and performances, and as an open implementing issue for the multi-agent framework.

To achieve shop floor reengineering agility, the manufacturing system is abstracted as compositions of modularized, reusable resources whose interactions are configured. These compositions will be modelled as teams of agentified manufacturing resources i.e. aggregated groups of motivated and collaborative agents whose behaviour is governed by coalition contracts. A team is automatically reconfigured by a resource broker agent, whenever a disruptive event occurs. The resource broker agent instantiates a Resource Service Access Model which collects and processes data about product execution, cost, quality, resource performance and power consumption.

The decentralized MES will be designed and implemented according to the PROSA reference architecture, and uses of the delegate multi-agent system pattern to accomplish its objectives. dMES is composed of three types of basic agents: product, resource and order agents, and allows the collaborative interaction with the staff agent which is implemented by the centralized SS, the Resource Service Access Model and the scheduling strategy commuting control. The dMES works with mobile WIP agents implemented on Intelligent Embedded Devices (IED) located on product carriers on the cell conveyor, which add intelligence to products and allow product-driven automation of the manufacturing processes.

The functional model of the semi-heterarchical MES will be tested on an industrial, 6-station demonstrative manufacturing cell in three types of experimental scenarios: with predicted, stable operating conditions; with unexpected disruptive events; with occurrence of rush orders. A feature tuning procedure for stability, sensitivity, nervousness, level of guidance and cost function selection is set up.

The novelty of the proposed service-oriented MES consists in its *dynamic switching* of scheduling modes while *reducing myopia and increasing sustainability* by weighting the resource participation in jobs function of the cost (consumed power and time) and quality of the services they provide (timeliness, accuracy). The holonic semi-heterarchical control model and multi-agent implementing framework assure *service orientation* of MES, which standardizes management and allows vertical integration of business & shop-floor processes.

1. TECHNICAL DESCRIPTION OF THE PROJECT

1.1 THE PROJECT TOPIC AND ITS PRACTICAL RELEVANCE

Today's global competition and rising prizes for resources force manufacturing companies to directly connect their IT-Systems (enterprise business layer) with their manufacturing plants (shop floor control layer), to provide higher business integration and enterprise agility. Thus, manufacturing enterprises need to adjust their business model and shop floor organization to be able to meet the fluctuating customer demand while keeping the overall costs as low as possible. This requires high *enterprise agility*, which is understood as the readiness of a company to adapt to new market requirements (Frick and Schubert, 2009). Agility corresponds to operating efficiently in competitive environment dominated by change and uncertainty. In this respect, *Manufacturing Execution Systems* (MES) have been used to manage not only the correct and autonomous execution of a plan of activities (Product Order - PO) or schedule, but also to efficiently respond to production changes and the occurrence of unexpected disturbances (Leitao and Restivo, 2006, 2008; Valckenaers et al., 2007; Novas et al., 2012). Most of the theoretical research done during the last two decades in the centralized scheduling domain is of limited use in practice (Sahardis, 2006). One of the main drawbacks of centralized scheduling systems (SS) is their lack of reactive capabilities and the inability to provide robust and detailed solutions in reasonable computational time. To efficiently address the scheduling execution problem found in real manufacturing domains, the horizontal integration (or collaboration) between SSs and MESs is a challenge that needs to be faced.

In addition to providing shop floor agility to business changes (market dynamics, rush orders, new product recipes, highly scalable mass customization), *shop floor reengineering*, based on configuration rather than on codification (reprogramming) should be feasible in MES control/supervision architecture (Barata, 2006). The shop floor reengineering approach consists in installing a resource-related agent-based architecture characterized by: *modularity* (manufacturing system for batch execution defined as variable compositions of modularized manufacturing components - building blocks), *configuration rather than programming* (system composition and its behaviour established by configuring the relationship among modules, using contractual mechanisms), *high reusability*, *legacy system migration*, and *sustainability* (considering resource timeliness, operation accuracy, power footprint and real-time consumption) (Borangiu, 2011, Barata 2006). Current MES development frameworks are based on implementing holonic reference architectures (e.g. PROSA, ADAcoR, HCBA, HAPBA, PROSIS, etc) and applying the Delegate Multi-Agent System pattern (D-MAS) (Van Brussel et al. 1998; Leitao, 2004; Panescu, 2011; Pujo, 2009).

Finally, since executing a product schedule (*operations sequencing* and *resource allocation* for a product's execution) involves a continuous update of the on-going agenda, MES *nervousness* is an inherent feature that should be considered. Schedule alterations are produced every time the agenda is updated (triggered by events such as: resource breakdown and recovery, storage depletion, a.o.). Research efforts should be oriented towards avoiding time-expensive full-scale revisions of in-progress plans while they are been executed - i.e. allowing only limited and accurate changes in the disrupted schedule, seeking for smooth shop floor operation and stability (Borangiu et al., 2009). Distributed MES (dMES) represent a solution proposed in this project to control system nervousness and assuring process stability; it uses *Distributed Intelligence* and *collective Decision*, thus implementing the heterarchical mode of product scheduling. The Distributed Intelligence is materialized through Intelligent Embedded Devices (IEDs) which add intelligence to the product during its entire execution lifecycle. IED assist products during their distributed scheduling and execution in a collective goal context (production stability, shop floor agility, limited working efficiency at work-in-progress level - WIP) – thus bringing closer the physical and decisional parts of entities composing a more performing, robust and agile control system.

This objective can only be achieved by combining the advantages of a centralized and sequential production control providing optimality over a long time horizon with the advantages of a decentralized production control model for agility and robustness (Sallez., 2010).

As we are entering the new era of highly instrumented, interconnected and intelligent manufacturing environment (resources, material flow) through Intelligent Products (Meyer et al., 2008) that add processing power to product execution, it is not only possible to implement both control strategies in the production cell (hierarchical and heterarchical), but to also dynamically switch between them as dictated by the current context. To solve this problem, semi-heterarchical control models (batch planning, product scheduling, routing and tracking) are proposed to rend a MES both globally optimized and agile with partially optimization at the level of products currently executed (WIP). Such new control architecture could provide centralized planning, agility and robustness through a mix of flexible and adaptive solutions on the automation layer (shop floor control) and on the IT layer (SCADA, MES, and ERP).

The practical relevance of the problem to be addressed is the optimality of production planning and resource scheduling and the availability of production systems. This is due to the fact that failures in technical systems cannot be avoided completely. This means that the entire cell needs to stop, at least until the planning is recalculated, with bad consequences on the production schedule.

The end-product offered through the project is the functional model of a generic semi-heterarchical MES installed and tested on a demonstrative 6-station industrial production cell

1.2 PROJECT CONTRIBUTION BEYOND THE STATE OF THE ART

The project proposes an interaction model allowing the cooperation between two different subsystems: a centralized scheduling system (SS) based on a selectable mixed planning & scheduling technology (e.g. constraint programming, production rules) and a decentralized manufacturing execution subsystem (dMES) based on holonic reference architecture and applying the delegate multi-agent pattern. This interaction model will be defined in terms of: events triggering new planning requests to the SS; bidirectional switching sequences between the hierarchical and heterarchical scheduling modes; decision mechanism for switching between scheduling modes; resource service access model weighting the resources' participation in work teams function of cost, cumulated load, power consumption, timeliness and quality of performed services. There will be also considered the tuning of the collaborative MES model: nervousness, centralized guidance level, mode switching, performance measure, societal inter-agent weighting mechanism. The collaborative model for SS - dMES interaction involves two layers depicted in Fig. 1.

The centralized scheduling system is in charge of generating a good quality global solution for a set of orders (batch) that must be processed on the shop floor. The system ensures that the main constraints related with the domain are satisfied (timing, assignment and topological restrictions. On the other hand, the decentralized execution system processes all tasks involved in the problem, including not only the manufacturing activities already scheduled by the SS, but also other relevant activities as transport, routing and storage tasks.

The MES executes the schedule - based on a certain predefined level of guidance - as it is initially delivered by the SS. The execution is carried out until a disruptive event occurs. At this point, because the current agenda is no longer feasible to be performed (because of alterations caused by unexpected situations), the MES should profit from new advice (on request) from the SS in order to continue the execution. This communication process has to be as fast as possible, because a long SS-dMES interaction time could cause the new schedule to be outdated, and hence no longer feasible to execute on the cell when it arrives. Therefore, the decision has to be taken in real time, i.e. the SS-dMES collaboration must be on-line

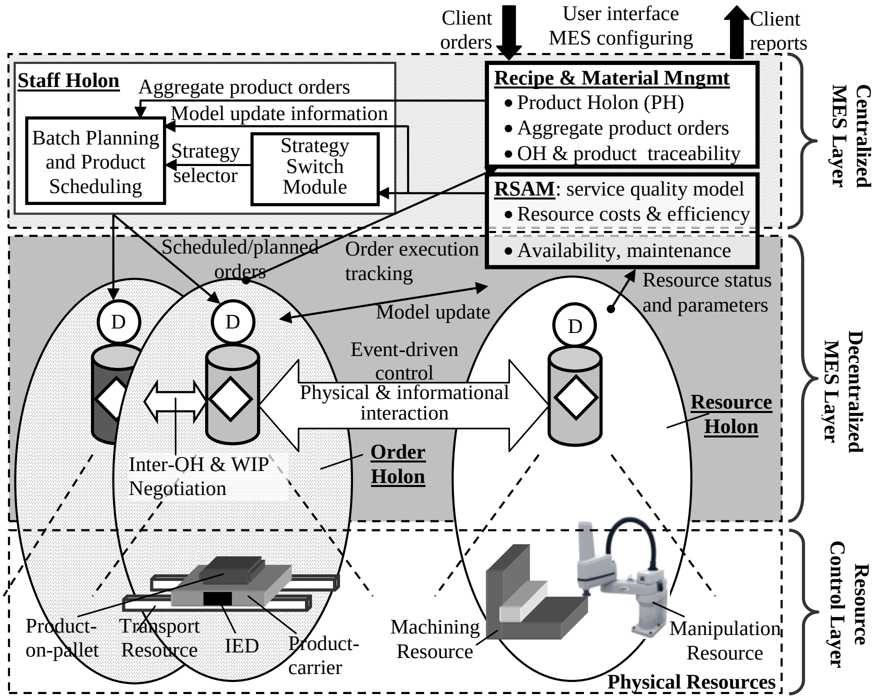

Fig. 1. The model of semi-heterarchical MES with SS-dMES dynamic interaction

The hierarchical MES is modelled as a centralized Holonic Manufacturing Execution System (HMES), i.e. as a holarchy integrating in software architecture the entire range of manufacturing tasks (order creation, recipe, material and resource management, batch planning, job scheduling and resource allocation, product routing and execution control, process and product tracking and preventive management). The holarchy will be defined as a system of holons implementing the PROSA reference architecture that can cooperate to achieve the production goal or objective. The manufacturing cell is broken down into three basic holons, the *Resource Holon* (RH), the *Product Holon* (PH), and the *Order Holon* (OH); each of these holons may exist more than once to fully define the job-shop structure. Order Holons will be created by a centralized Scheduling System (SS) from an aggregate list of product orders generated at the ERP level of the enterprise. SS will be considered as *Staff Holon* (Fig. 2).

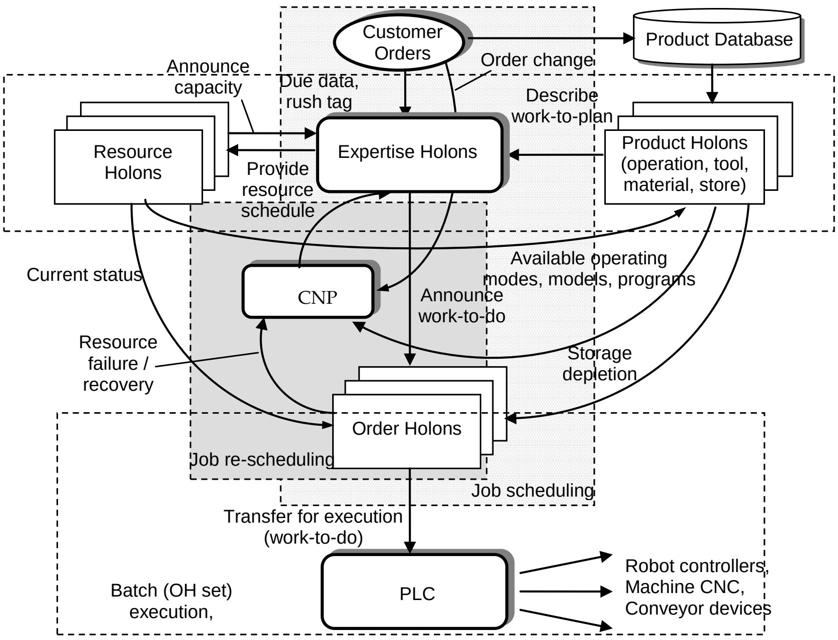

Fig. 2. The holarchy for HMES development

The control architecture proposed on the decentralized MES layer (Fig. 1), called "open-control", has the advantage of augmenting traditional explicit control with a new kind of control - "implicit control". In this paradigm, entities can be strictly controlled hierarchically and, at the same time, they can be influenced in heterarchical mode by their environment ("environmental control") and/or by other entities ("societal control"). This feature allows designing control systems that are both agile and globally optimized, thus reducing the myopic behaviour of self-organized architectures and increasing the agility of traditional architectures. combining the two types of control in the same architecture creates new challenges since the two types of control must now be managed and integrated within the larger control paradigm.

The implicit *societal control* will be performed in two ways. The first one involves fine tuning the partial view of a collective property inside an entity representing the *service sequence* and *providers* (set of physical resources) to manufacture a product. This modification can be seen as an internal influence that modifies the entity's behaviour. This behavioural modification then influences the other entities via the societal optimization mechanism, which is supported by dialogue. For example, the controller can force a specific product type to be machined on a specific resource, which implies changing the dynamic of the allocation process for the other products. The second way involves changing the dynamics of the dialogue in the societal optimization mechanism by modifying the dialogue parameters of these entities (active WIP agents that evolve in Holon Orders after real-time scheduling within the product-driven automation layer of the system). For example, in a contract-net context, a product can interrogate all the resources or only those resources in its proximity. This second way has a direct impact on the overall collective performance.

To achieve shop floor reengineering agility, the manufacturing system will be abstracted as compositions of modularized reusable resources whose interactions are specified by configuration. These compositions are modelled as teams of agentified manufacturing resources i.e. aggregated groups of motivated and collaborative agents whose behaviour is governed by coalition contracts. The resource teams will be initially configured by help of a graphical user interface; a team is automatically reconfigured by a resource broker agent, whenever a disruptive event occurs, such as resource breakdown, entering early maintenance or featuring significant degradation of its performances or quality of performed services. The resource broker agent will instantiate a Resource Service Access Model (RSAM) which collects and processes data about product execution, cost and quality, resources’ status, performance and power consumption.

For this purpose, a highly instrumented working environment will be created, in which smart meters monitor the energy consumption of machines, robots, conveyor belts during their operations. The degree of preference for resources, computed by the RSAM, will consider the costs of services they perform; cost factors result by comparing the resource's energy footprint with the real power consumption for each operation performed. The resource participation in job negotiating is correspondingly weighted, and will permit the optimization of mixed global cost functions (e.g. simultaneous minimization of execution time and consumed energy) for sustainability. A combined energy consumption factor and quality control factor will be also used as decision support for preventive maintenance of the shop floor resources. The smart metering system will be implemented on the demonstrative manufacturing cell.

Based on prediction models for unexpected situations and atypical conditions detected by the HMES process monitoring subsystem and decoded by the RSAM agent, a supervisory model predictive control framework will be developed to ensure uninterrupted process operation at in the event of performance degradation, increase of power consumption, early maintenance need or resource breakdown. The design is based on the Risk and Hazard control (RHC) approach, and will generate corresponding actions to be performed by the MES Job & Dispatching Management subsystem for optimized routing of job orders through available resources. The information on resources' maintenance history is reported and optionally exported to external systems, e.g. to the ERP system. The RHC configuring of initial preventive maintenance time periods and actions will be done by customization of the Graphical User Interface.

The centralized MES will be designed based on a Service Oriented Architecture (SOA), which enables rich extensibility and connectivity to external applications. Within this application single services will be realized by combining standard components which communicate using Web services. In order to interface with other components, the MES will be adapted by using, providing and consuming Web services. In order to customize and extend the MES, the business logic will use an innovative Workflow Manager; the Workflow Manager will contain the business logic in versioned workflows, which allows the easy adaption of the system to customers' needs. Changes in business logic which may happen over time can be thus operated in the system by adapting workflows. The design of the centralized MES will include a MES Fabrication Monitoring subsystem enabling the graphical online display of the current shop floor status. This will include all resources and production orders currently executed on the production line, cluster, and equipment. The zooming will be customized to visualize the equipment status and process data, such as products ("runs") on the equipment.

The Scheduling System (SS) will be developed using constraint programming technology, which comprises computational implementations of algorithms to tackle constraint satisfaction problems. SS is implemented as a MES **Advanced Planning & Scheduler** (APS) to enable a smooth planning and allocation of manufacturing resources considering all essential restrictions (hard constrains) from the shop floor.

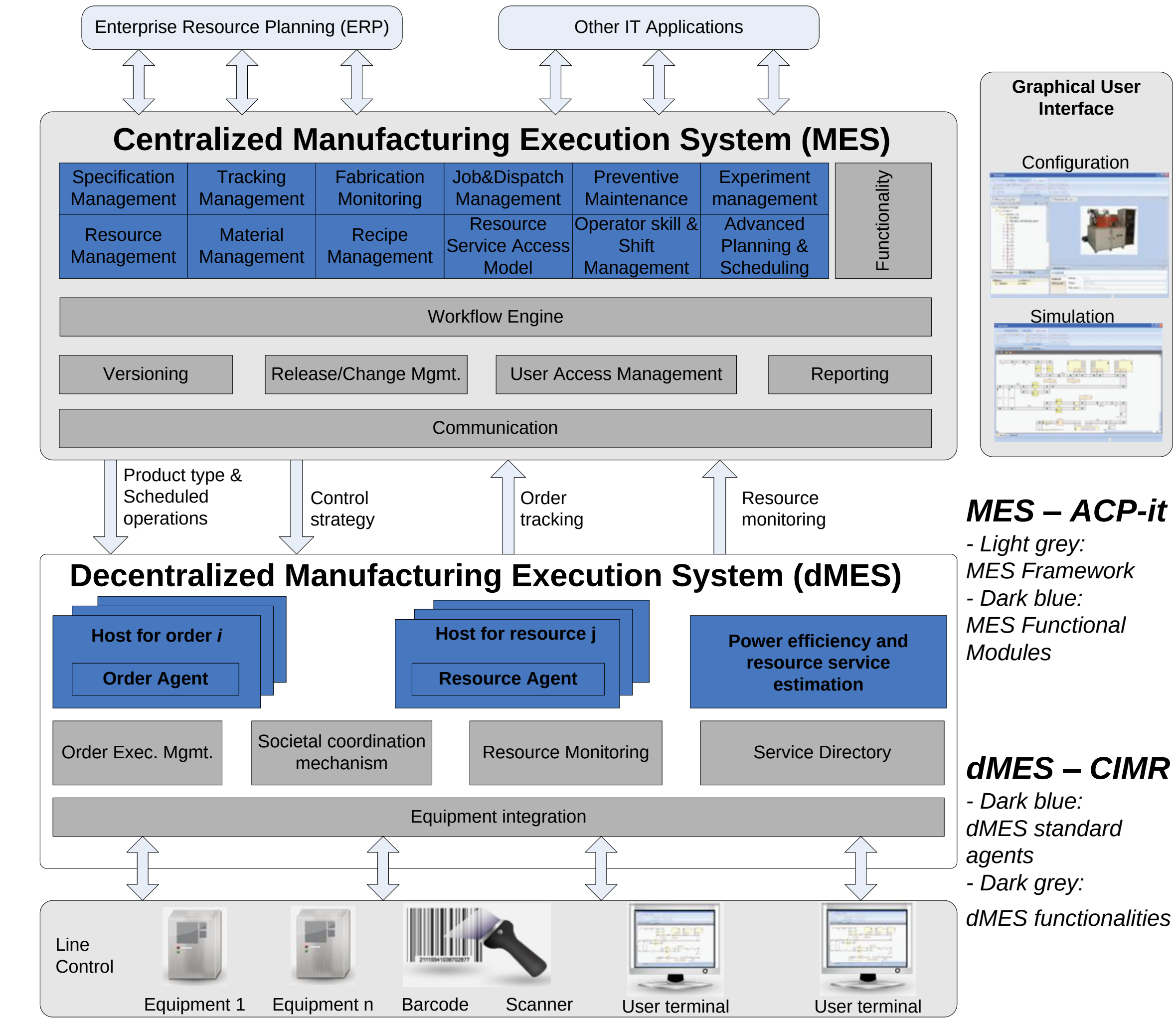

Fig.3. Architecture of the semi-heterarchical MES: optimal on long term, reactive & agile on short term

The following application areas will be covered by the APS: (1) Release/Demand Planning to support the user in the optimization of the product mix and lot start planning, due date planning and inventory forecasting and to forecast resource utilization; (2) Human Resource

Planning for optimal allocation of operators to processing tasks and maintenance activities; (3) Maintenance Scheduling for task allocation and scheduling considering resource utilization, especially temporary bottleneck situations; (4) Online Rescheduling and ad-hoc Dispatching based on unforeseen events. Fig. 3 shows these subsystems integrated in the semi-heterarchical MES.

To solve the lack of reactive capabilities while preserving optimality on as far as possible horizons, and thus reducing the myopia of existing MES, as well as compensating their inability to provide robust and detailed solutions in a reasonable computational time, a collaborative mechanism will connect the SS with a distributed MES (dMES) in a semi-heterarchical control topology.

During execution time, a new type of lightweight agent - called WIP (*Work in Progress agent*) is automatically created whenever the fabrication of a new product is launched. WIP are mobile agents, located in Intelligent Embedded Devices (IED) and augmenting the product carrier (pallet carrier) on which the product is progressively created. Thus, an Intelligent Product (IP) model will be created by embedding intelligence in the order holon (OH) transferred to the IED from the centralized Scheduling System (in hierarchical scheduling mode) or in the OH created in line by the WIP agent (in heterarchical scheduling mode).

WIP agents virtually execute the fabrication stages for their associated product, inquiring the resources about their availability and capabilities, and the RSAM about the updated costs of the services they provide. Upon receiving answers for these inquiries, WIP agents search the best schedule and:

- report their solution to the order agent transferred from the SS in hierarchical mode; if the solution is significantly better than the one embedded in the existing order agent, the WIP solution will replace the SS solution, and a rescheduling command is issued to the SS;
- create directly an order agent from the best WIP computed solution in pure heterarchical mode, case in which two scheduling strategies will be developed: (i) with local optimization of the overall work-in-progress; (ii) with resource load balancing by scheduling always only the next operation on products.

The WIP search activity requires designing and implementing data exchange sequences and inter-IED communication. When operating in heterarchical mode, all the schedules computed from a local point of view must be synchronized in order to eliminate resources overlaps. This synchronization is done by an elected *mediator agent*, its functionality being taken successively by OHs in execution; it is hosted by a decentralized platform running on several machines making it a suitable component of the dMES. An extended FIPA contract Net Protocol framework will be developed for order agent (OH) creation and execution.

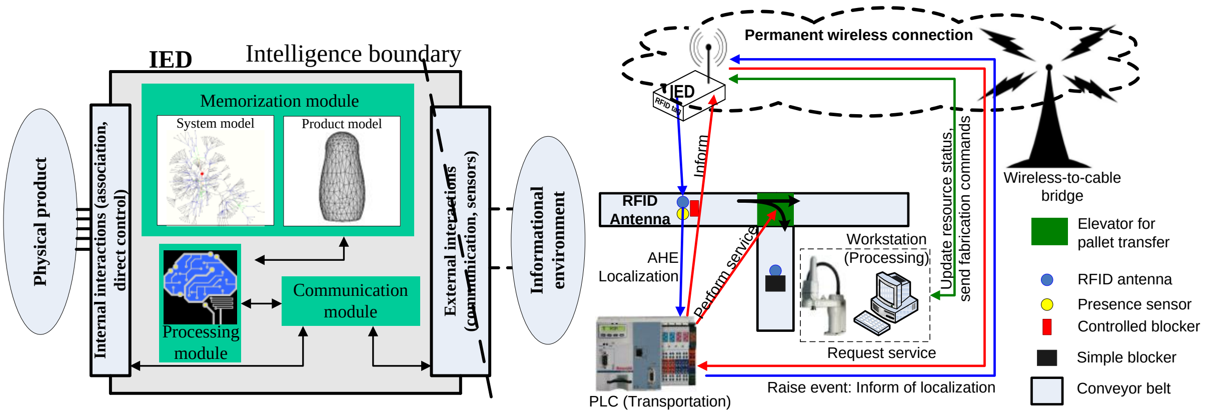

Fig. 4. Structure of the intelligent embedded device augmenting the Order Holon with active behaviour

The IP model uses a 5-attribute approach [product #ID; current location; memorization of operations set; operations precedence list; communication with co-existing WIP agents and

RSAM; reasoning and decision taking for operation sequencing and resource allocation] and requires the specification of the related data sets and format, functions, information exchanges and contractual mechanisms with the co-existing WIP agents.

The IP model will be implemented with Intelligent Embedded Devices (IED) which use augmentation modules designed as embedded processors composed by a memorization module, a module for RFID communication and a real-time processing module. The IED will be located on the product carrier, and will host both the order agent (received from the SS or created through heterarchical interaction of all WIP agents) and the WIP agent associated to the individual product (Fig. 4).

The IED's real-time operating system will be developed in open source approach. For the decisional software part, the Java Agent Development Framework will be used since it was specially designed for developing multi-agent systems and applications conforming to FIPA standards for intelligent agents (www.fipa.org). The core of the 2-layer command and IED control model contains four decisional entities: OH container, WIP container, Resource container and RSAM main container, implemented as agents in JADE running over generic cross platform Java Virtual Machines (VM).

The process of associating a software agent to a physical entity, creating thus what is called in the manufacturing domain a holon, is called agentification and consists of associating to each control entity a software agent in charge with the decision making process and with the communication through a standard medium. These agents will be seen as automation objects – abstraction of mechanical devices with encapsulated intelligence (Obitko et al., 2002) allowing thus component reusability. This architecture will allow:

- *Decentralized order execution management*: each OH will automatically trace its execution path and store the results of the received operations.
- *Societal coordination mechanism*: synchronization of the heterarchical structure's composing entities through a direct dialogue between them based on a common ontology.
- *Resource monitoring*: allows storing information about resource status and behaviour.
- *Service directory*: permits centralization of the services offered by the manufacturing system resources (a yellow pages type of service).
- *Reducing the myopia of the global MES*: as the SS is a staff agent, at a rescheduling time point (resource breakdown, performance degradation calling for early maintenance or significant better solution found by the WIP agents) the dMES calls the SS to solve a new scheduling problem for the remaining products, while continuing to run production following the collective decisions of the WIP agents.

In order to model the job-shop for the semi-heterarchical MES, a testbed modelling tool will be developed. This job-shop simulation framework is based on models of typical shop floor devices (industrial robot manipulators (SCARA, anthropomorphic) with several types of grippers and tools, machine tools with local magazines, conveyor belts, stoppers, lifts, a.o.) and on standard interfaces and communication protocols connecting the virtual shop-floor equipment to the control part of the MES.

Finally, the device-control simulation models will be integrated in an application implementing the virtual production system [(shop floor equipment + MES) - job-shop type product execution] with evaluation of performances.

The semi-heterarchical MES, installed and connected to a demonstrative, 6-workstation robotized Flexible Manufacturing Cell (FMCell) will be tested in three types of experimental scenarios: (a) with predicted operating conditions, without any perturbation; (b) with unexpected disruptive events (resource failure / breakdown / performance degradation / exceeding allowed power consumption); (c) with occurrence of rush orders.

The system's control performances will be estimated during the design stage, to set up a feature tuning procedure for stability, sensitivity, nervousness, level of guidance and cost function selection.

1.3 PROJECT OBJECTIVES AND OUTCOMES

The objectives proposed in the **SoEA4M** project are:

1. Development of a semi-heterarchical control model for agile and robust manufacturing, with mixed batch planning and product scheduling
   - Defining functionalities, performances and evaluation metrics for the control system
   - Specification of the semi-heterarchical control concept and solution development
   - Defining the components of the generic control model: holon classes and holarchy, agent types and multi-agent framework, mode switching mechanism, communication
2. Defining the mixed batch planning and product scheduling scheme for myopia reduction
   - Management of rush orders
   - Real-time product scheduling through agent collaboration
   - Dynamic, event triggered switching of the scheduling modes
   - Designing the collaborative System Scheduling (SS) - distributed Manufacturing Execution System (dMES) framework
   - Tuning agents: measuring service levels
3. Developing the job shop simulation framework
   - Developing simulation models for material processing, manipulating and transport devices
   - Creating APIs for interconnection of the simulation modules to the MES
   - Integration of the simulation models in virtual job-shop type production structure
4. Designing and implementing the centralized Manufacturing Execution System (MES)
   - Optimal batch planning and product scheduling - design of the centralized planner
   - Developing the job and dispatch management subsystem
   - Designing the recipe, material and resource management subsystem
   - Developing the Resource Services Access Model (RSAM) for resource broker agents
   - Designing the fabrication monitoring and production tracking subsystems
5. Design and implementing the generic dMES with product-driven automation capabilities
   - Defining the Intelligent Product (IP) concept: functions, information, data sets
   - Implementation of IP with Intelligent Embedded Devices (IED)
   - collaborative inter-agent decision taking through service orientation
   - Design of the product-driven automation scheme based on infotronics
6. Extending the MES with the Risk and Hazard control system based on RSAM
   - Estimating the power efficiency of resources via smart metering
   - Creating the performance model for resource efficiency and service quality in the RSAM, to be used by the resource broker
   - Predicting the unexpected from the RSAM: the predictions model for unexpected situations and atypical conditions
   - Decision taking for predictive resource maintenance
7. Implementing and testing the functional model of the semi-heterarchical MES on an experimental, demonstrative industrial manufacturing cell of job-shop type
   - Installing and interconnecting the centralized MES and the distributed dMES with the Flexible Manufacturing Cell equipment
   - Scenario definition: products, operations [CNC machining, robot assembling, vision-based quality inspection], disruptive events: resource breakdown / recovery, storage depletion, occurrence of rush orders
   - Experimenting, testing and evaluating the functional model MES in normal and disturbed conditions; performance evaluation and solution validation
   - Creating the technical documentation and of the semi-heterarchical MES, extended with experiments report and technical data and performance sheet
8. Dissemination of results
   - Participating with scientific papers in representative national and international scientific events in the project's domain

- Publishing scientific articles in journals with impact factor
- Interconnecting the project's consortium with international R&D organizations, research labs of academic institutions and companies
- Organizing an Exploratory Workshop on "MES Benchmarking" with international participation
- Organizing a Technical Day for Industry: "Integrated Information and control Systems for Smarter Enterprise" to demonstrate the functionality and utility of the functional model MES (proof of concepts, demos)

By carrying out the project, important scientific and technical limitations featured by existing MES systems will be overcome: lack of agility and robustness of pure centralized control architectures, myopia of totally distributed MES with heterarchical scheduling, unfeasible centralized schedules due to performance degradation of resources.

One major scientific contribution of the project is the development of a prediction model for unexpected situations and atypical conditions which might arise during the production process. The project's value also resides in the double functionality provided by the Resource Service Access Model: (a) weighting the resources' participation in the bidding process of job allocation for product execution - taking into account the permanently updated history of their performances and quality of provided services; (b) predictive maintenance of the resources - signalling the need for early maintenance of those resources which significantly exceed the power consumption in comparison with their standard estimated energy footprints.

One technical advantage of the proposed semi-heterarchical MES over existing solutions results from the implementing mode of the semi-heterarchical scheduling concept: any hierarchically computed schedule, even at long-time horizon, will be treated only as a recommendation, and checked against on line created solutions; this means that the global objectives of the production systems initially featuring a high level of performance are kept at the same performance standard by permanently updating the schedules depending on the resources' technical status which is reflected in product accuracy, execution times and power consumption.

The project outcomes are:

1. A design methodology of semi-heterarchical Manufacturing Execution Systems for shop-floor structures, with dynamic, event-triggered switching between hierarchic and heterarchical modes
2. A centralized MES with optimal mixed batch planning & product scheduling installed on an demonstrative 6-workstation industrial Flexible Manufacturing Cell (FMCell)
3. A decentralized, heterarchical dMES with intelligent embedded devices, implemented in a multi-agent framework, reducing the shop floor myopia in heterarchical operating mode
4. A resource (machines, robots, conveyor belts) power efficiency monitoring system based on smart metering and task-related energy footprint evaluation
5. A Resource Service Access Model continuously monitoring the quality of resource services and their power efficiency for allocation decisions taken by the resource broker (performance-driven shop floor reconfiguring)
6. A Risk and Hazard control system based on the RSAM for predictive resource maintenance
7. A functional model of the semi-heterarchical MES, installed, integrated and tested in a 6-station industrial, robotized FMCell with job-shop layout.

1.4 ORIGINAL AND INNOVATIVE CONTRIBUTIONS OF THE PROJECT

The SoEA4M project's outcomes are original in terms of the: conceptual approach and design of the semi-heterarchical control model, solution for myopia reduction, and management of the variable time window for scheduling. The implementing solutions are innovative: using the multi-agent technology for resource team (re)configuring and thus providing reengineering capabilities for the shop-floor physical structure; imposing service orientation to the two MES subsystems (SS and dMES) - by componentization of the product planning, scheduling, execution and tracking tasks, mapping them as software services and efficiently coordinating them through orchestration and choreography tools.

One original aspect of the project outcomes resides in creating the Intelligent Product concept (functionality, data types and sets, connectivity with external information sources and systems, and aggregation degree), and the framework for product-driven automation of the manufacturing processes.

1.5 INTER-, MULTI-, OR TRANS- DISCIPLINARY CHARACTERISTICS

The disciplinary components of the project are dominated by a systemic approach materialized through a distributed intelligence automation solutions (DIAS) - a trend in future manufacturing control systems. The main DIAS framework used in the project is the multi-agent technology, correlated in an interdisciplinary approach with the domains: holonic manufacturing; robotized processes; CNC machining; group technology; computer Aided Process Planning (CAPP) and Quality control (CAQC); Service Oriented Architectures; smart metering and energy efficiency; organizational service innovation.

The scientific disciplines corresponding to these domains are: Systems Engineering, Industrial Engineering, computer Engineering, Information Technology and communication and Power Engineering. They are the facets of an interdisciplinary representation in the project because they address respectively its main goal (efficient control), the plant and application on which the control is applied (manufacturing shop floor), the framework and tools developed for the control (agentification of resources, products and processes, the multi-agent solution), which is intended to provide sustainable process structures (energy efficiency).

These engineering characteristics are combined in the project with business and management ones, in a service-oriented approach.

The aims of the project are to integrate and interconnect scientific disciplines and technical skills displayed by using members of the consortium of complementary scientific areas related to manufacturing systems control.

Regarding the trans-disciplinary nature, not to be confused with interdisciplinary and multidisciplinary integration of disciplinary concerns, it should be noted what is simultaneously within various disciplines, in this case, automation, computer science, computers programming, etc. So finally the integration of numerous inter-domains, multi-disciplinary and cross-disciplinary has trans-disciplinary characteristics.

Moreover the ability to research, develop, deliver and create prerequisites for implementing a control solution in an undeveloped market is also an important challenge.

2. IMPACT AND DISSEMINATION OF THE PROJECT RESULTS

2.1 DISSEMINATION AND EXPLOITATION OF THE PROJECT RESULTS

The partners composing the team – UNIVERSITY (CIMR Res. Centre) and COMPANY (acp-IT) havemplementary experience in fields of dissemination and capitalization of the developed research solutions. The CIMR research centre has experience both in developing prototypes and customized solutions in the field of decentralized plant control and monitoring and organizing scientific and technical events for the purpose of knowledge dissemination, promoting scientific achievements, marketing of products and services and technological transfer. The industrial partner acp-IT is focused on developing industrial applications for plant control and monitoring, and marketing of the IT products developed by the German company acp-IT for clients.

The partners will establish in the first month of the project a common dissemination strategy based on the scientific contacts of CIMR and the business ones of the industry partner acp-IT.

The dissemination of the project's results will be a continuous process spanning over the entire project duration with an increased activity in the last two stages of the project. This process will gather the partners developments, outcomes and good practices in order to make them available to the national and international scientific and technical community, as well as to the industry good manufacturers, services providers. The main activities of result dissemination include:

- Presentation of papers at prestigious international conferences organized in the country and abroad; these presentation will include demonstrations and case studies about the utilization of the generic MES in industrial applications.
- Publication of partial research results in important journals with impact factor, accessed by a large number of specialists - developers and integrators of high-tech manufacturing control and monitoring systems, customers - specialists from production enterprises, supply and service providing companies.
- Organization of dedicated technical events with proof of concepts and demonstrative sessions, at national level. These direct dissemination forms will be organized as benchmarking and technical days in the R&D Laboratory of CIMR, with practical demonstrations carried out on the 6-station robotized manufacturing cell on which the semi-heterarchical control system developed in the project will be installed
- Presentation of the characteristics, functionalities, capabilities and technical performances of the functional model MES on several knowledge and innovation dissemination platforms: the project's website created and managed by the project coordinator, the Service Innovation Business section SS-KE of the INSER@SPACE knowledge platform of the University Politehnica of Bucharest, the acp-IT website and the Siemens Partnet, the newsletters of the Institute of Manufacturing, Cambridge (IfM), the Cambridge Service Alliance (CSA), IMS2 / GdR-MACS, and of the national technical organizations SRAIT (Romanian Society of Automation and Technical Informatics), SRR (Romanian Society of Robotics) and SRM (Romanian Society of Mechanics). Great attention will be paid to dissemination activities involving internet-based tools. The project website that will be developed to be used for dissemination purposes within the consortium and to the general public. Also, an important tool will consist of the initiation of a virtual community for the identification of potential users who will provide essential feedback throughout the project development.

Along with the previous dissemination activities, the introduction of the project's main scientific achievements in the AOSI (Service Oriented Enterprise Architectures) and SEM (Service Engineering and Management) Master programs curricula, organized at the University Politehnica of Bucharest, the Faculty of Automatic control and computer Science will assure a wider target audience.

Market-oriented dissemination forms will benefit from the acp-IT experience, tradition and methods established during the last years with industry clients - leading companies: SAP Industry Group, Siemens A.G., Audi A.G., food producing and packaging companies, logistics and supply chain companies from European countries.

During the development of the SoEA4M project, there will be established strong liaisons with research, academia and decision making groups from industry to develop consensus on standard further development.

Standardization will be an important objective of the project, in order to assure interoperability of the internal shop floor databases and application modules with the different external databases to which the semi-heterarchical MES will have access and portability of the MES management, control and maintenance software modules on equipment available from different producers. Thus, the partners will elaborate a common standardisation strategy, identifying relevant standardisation bodies and, for each of them, deciding on the appropriate level of participation (active contribution, active attendance, passive follow-up).

Also, the cooperation with leading professional and scientific organizations (the French Workgroup "Intelligent Manufacturing Systems and Services" - IMS2 of GdR-MACS, the British "Institute for Manufacturing" of Cambridge or the "Siemens Partnet" and the "Light Roll Partner" organization) in this standardization activity will improve the capability to produce roadmaps and brand-new solutions to solve those issues that the project is expected to raise in the current standards. It is intended to have a first viewpoint on the standardisation strategy in the first month of the project; this initial approach will be periodically revised and updated, each WP being expected to provide extensions to feed standardisation activities.

As was presented in the last WP, the exploitation of the project results will be done through: (1) direct capitalization on the intern and extern markets, the partners and customers of acp-IT being the first to benefit from the developments done within this project; (2) the utilization of the results in higher education and research, for course enrichment in the AOSI and SEM master programs.

<u>Initial plan of result exploitation</u>: the partners will pursue in common the exploitation of the project results. An initial exploitation plan per partner will be agreed and published during month 3 of the project and will be updated whenever a major development in the project is achieved. The exploitation and dissemination activities will be correlated in order to maximize the project impacts on the market and the developers' community.

<u>Technology transfer actions</u>: the two partners of the consortium are committed to carry out technology transfer actions regarding the project outcomes, within the bounding conditions that will be described in the consortium Agreement.

<u>Patent filing</u>: as a necessary step to be carried out before the exploitation of results, the partners will patent the functional model of the MES and a number of developed solutions and major subsystems, identified as well-defined elements with future trading perspectives.

There will be realized activities for the exploitation of SoEA4M project results throughout the project development, which consist in:

- Defining and carrying out three complex sets of experiments in which the solutions developed will be tested and validated and their performance evaluated.
- Setting up standard testing procedures for the SS and dMES subsystems for performance and reliability evaluation and validation.
- Validation of a search mechanism in a web – based library allowing to locate algorithms, procedures and routines which are relevant to a certain type of function.
- Setting up tests with of the functional model of the MES on a demonstrative, industrial manufacturing structure featuring real operation sets and having standard industry capabilities.

2.2 POSSIBLE APPLICATIONS WITH MARKET POTENTIAL

The main scientific and technological results of the project will significantly contribute to the progress of Romanian community of high-tech solutions developers and integrators, with impact on the national manufacturing industry and enterprises having a production profile. The semi-heterarchical MES represents the best possible manufacturing control solution, featuring at the same time: economic efficiency, agility to market changes, adaptability to variability of products and customer orders, integration of predictive maintenance and robustness to unexpected situations, as well as increasing the sustainability of production structures.

The solution is implemented and realized as a functional model, being tested on a real industrial manufacturing structure - a robotized cell. The developed system is generic, modular, being designed to offer interoperability and portability on heterogeneous factory equipment; for these reasons, the developed MES has a high potential of commercialization for the production enterprise market.

This trading perspective applies for the following industries: automotive, food, pharmaceutical, electrical equipment (assembly), material processing and materials with special properties (e.g. nuclear). The important position of partner P2 - acp-IT in the manufacturing and automation systems market will positively influence the perspective of MES commercialization.

Creating a strong collaborative platform between the members of the consortium, bringing together the members of a research centre and an economic agent involved in the project and facilitating the information flow within the consortium in order to achieve the project goals.

2.3 ESTIMATED IMPROVEMENTS IN THE QUALITY OF LIFE, WITH RESPECT TO CURRENT PERFORMANCE OF PRODUCTS, TECHNOLOGIES AND/OR SERVICES

The main result of this project is a new and innovative product - the semi-heterachical MES and its independent major components: the centralized MES and the heterarchical distributed MES - which offer a new approach in the control of distributed production structures, by offering a more flexible and adaptive way to respond on heterogenic production types. The control solution based on distributed intelligence, the conceptual model of semi-heterarchical control and its multi-agent implementation contribute to the agility and robustness of the production structure, with improvements of its management and providing organizational innovation. Beyond these improvements, the main benefit for the community resides in the sustainability of production structures with respect to the market dynamics.

The project contributes to the improvement of the working conditions of the operating and maintenance personnel in production enterprises, due to the Risk and Hazard control functionality and capabilities of the prediction model for unexpected technical situations; these features will help minimizing the occurrence of potentially harmful situations, both for the factory environment and for the personnel.

2.4 PROJECT INTEGRATION IN THE DEVELOPMENT STRATEGY OF PARTNER COMPANIES

The development strategy of acp-IT is to bring innovative solutions to the most competitive industries: semiconductors, photovoltaic, automotive, electronics, and manufacturing. The customers of acp-IT grow their business by: (i) developing innovative ways to bring value back to society by their products and services and (ii) being competitive in technology, quality of products and costs. acp-IT, as a supplier for these industries, must constantly develop innovative solution to bring value for the business of its clients through IT solutions, vertical integration of enterprise business and production processes, and sustainability of resources and shop floor structures.

With its service and product portfolio, acp-IT focuses on markets with complex, partly or highly automated production environments and varying product range. Target industrial sectors of acp-IT include Photovoltaic, Semiconductor, Automotive, Electronics Manufacturing, Lab Automation as well as further high tech fabrication areas. In all sectors acp-IT constantly improves its industry and related IT knowledge to be able to keep up with new innovations and be leading edge with regard to acp-IT's professional IT solutions and services.

The proposed MES, featuring a powerful set of reconfigurable software components to provide economic efficiency, agility and support a high bandwidth of diverse manufacturing industries and processes is in strong correlation with the above described development strategy of the acp-IT partner.

One global need of acp-IT is to provide for its industrial clients rich functionalities combined with easy usability in the area of production planning, monitoring and control for high-tech fabrication sites. The main outcome of the project - the semi-heterarchical control solution, model, design and implementation - fully corresponds to this need. In particular, the company needs solutions for product-driven automation, distributed control and a more flexible and agile operating mode of the job-shop MES platforms it produces. acp-IT also needs smart monitoring solutions for the energy consumptions of resources, to enhance the predictive maintenance functionality integrated in its MES systems. All these needs are addressed by the topics and outcomes of the project.

All acp-IT customers benefit from this cross-industry experience. Identifying best practices and understanding their point in order to customize optimally the company's products according customer's requirements makes a successful business. That is why acp-IT banks on cross-industry knowledge exchange offered in the framework of the SoEA4M project.

2.5 INTELLECTUAL PROPERTY PROTECTION

The appropriate handling of Intellectual Property Rights (IPR) is critical to the success of the SoEA4M project. The ideas exposed here have been discussed and agreed by the consortium members and will be properly incorporated in the consortium Agreement which will be signed by the partners prior to the project start.

The consortium's decisions on the matter of IPR are based on two main principles:

- Fairness: IPRs belong to the entities that achieve the technical development.
- Functionality: IPRs are protected with the aim to obtain return on investment by means of their commercial exploitation. The distribution of the exploitation rights on the IPR will comply to facilitate an agile commercial exploitation, avoiding complex decision making structures that can act in detriment of times to market.

The consortium has worked to develop the best possible approach based on both principles. Within this context, IPR related to project results will be shared amongst the two partners based on their position in the future added value chain and their implication in R&D activities for obtaining those results. Below are drafted the key principles of the consortium Agreement regarding the subject of IPR management.

A. confidentiality:

A clause providing for a protection period that will be:

- The longest of (i) the period of the Grant Agreement plus 2 years or (ii) 5 years from the effective date of the Grant Agreement or
- If no Grant Agreement is signed, 5 years from the effective date of the consortium agreement, should be integrated.

B. IPR protection and handling:

Foreground, which is generated by more than one party such that it is impossible to separate them for the purpose of IPR protection, shall, unless otherwise agreed, be owned jointly by the parties generating such Foreground. Each joint owner may Use such Foreground and grant non-exclusive licences to third parties to do so without being obliged to account to the other joint owner or to demand his consent.

Specific Background may be excluded by a party by agreement prior to signature of the Grant Agreement.

Access Rights by a party to the Background or side ground of another party needed for the use of Foreground shall be granted by that other party on fair and reasonable conditions to be contained in specific written agreements between the parties. "Side ground" shall mean information other than Foreground developed or otherwise acquired by a Party after entering into the Grant Agreement, as well as copyright or other IPRs pertaining to such information.

All of the provisions of the Grant Agreement and consortium Agreement concerning Access Rights shall apply equally to software. Access Rights to the source code of such software will only be required to be granted to the extent expressly so provided in the consortium Agreement. Furthermore, specific licence rights and specific sub-licensing rights shall be specified in relation to software that is Background, side ground or Foreground.

No party will have the right to publish or allow the publishing of any data which constitutes Foreground, side ground, Background or confidential information of the other party, even where such data is amalgamated with such first party's Foreground, side ground, Background or other information, document or material. A copy of any proposed publication in connection with or relating to the project shall be sent to the coordinator; the parties may object to the publication within a stated period on the basis that that it adversely affects the objecting party's Foreground or commercial interests or includes its confidential Information.

C. Liabilities:

Parties should agree on an appropriate limitation of liabilities under the consortium Agreement. For certain cases of breach the normal limits will be increased or will not be applicable at all, such as the case where the liability involves the use of any party's IPR outside the scope of the relevant Access Rights.

D. Amendments to the Grant Agreement or the consortium Agreement:

Amendments to the Grant Agreement or the consortium agreement may only be made with the specific written agreement of the parties.

3. CONSORTIUM DESCRIPTION

3.1 coNSORTIUM STRUCTURE

P1: Engineering UNIVERSITY (CIMR R&D Centre)

P2: High Tech COMPANY (acp-IT – Industry Systems and Services)

3.2 CONSORTIUM COMPLEMENTARITIES AND SYNERGIES BETWEEN PARTNERS

The consortium partners envisage achieving the project's objectives common targets based on their complementary activities. CIMR and acp-IT have strong background in information technology applied to real time process control, new and innovative services in software. CIMR has also an extensive background in theoretical approach of distributed intelligence for process control, multi-agent system technology, feature-based description of material flows and artificial intelligence applied to predictive maintenance and quality control.

The acp-IT team has competencies in group technology, manufacturing equipment, real-time process control, centralized MES design, risk and hazard assessment, and emergency management systems. Being a commercial company, acp-IT has good knowledge of customer's needs.

CIMR has experience in designing product-driven automation systems and has already developed a framework for Intelligent Product monitoring over the execution lifecycle. acp-IT is recognized not only for its process control, customer relation management, user interfaces and predictive models developments, but also in promoting new technologies: Web, cloud, SOA, and service orientation of technical processes for total integration with business processes at enterprise level.

The most important synergy between partners is the approach for system integration based on open source, common platforms, use of standards and innovative technologies.

4. PROJECT MANAGEMENT

4.1 Management structure and procedures

This section details the overall Ma4MESpda project management structure including the internal organization, the roles and responsibilities of those involved, the implementation management and the procedures for conflict resolution and decision-making.

Organizational structure

The management structure is grouped into 2 levels, with its specific bodies for management:

- Executive level: Project Management Board (PMB) comprising Project Director, Technical Manager (TM), Quality Manager (QM), Risk Manager (RM) and Project Office (PO) is in charge of making decisions regarding the daily development of the project.
- Operational level: Operational management team (OMT) with the Work Package Leaders (WPL) and Task Leaders (TL) will be in charge of making decisions regarding the daily development of a specific working or research activity.

Executive level

The PMB takes strategic decisions. The Project Director is the person who leads PMB work and holds the higher executive management responsibility. TM, QM, RM and PO are staff bodies for the PMB, taking care of technical, quality, risk, administrative and reporting issues respectively.

<table>
<tr><th colspan="2">Project Management Board (PMB)</th></tr>
<tr><td>Activities</td><td>• Prepare the Activity Plan; coordinate the technical work of the WPs.
• consolidate progress reports to be submitted to the authority (as defined by the project agreements).
• Approve the project deliverables.
• Propose changes to the project (if needed).
• Proposes key performance indicators and evaluation with regard to these criteria.</td></tr>
<tr><td>Composition</td><td>• Chairman: Project Director, Members: TM, QM, RM, WPL, and PO (nominated from P1 and P2).</td></tr>
<tr><td>Organisation</td><td>• Meetings: four meetings per year, complemented by at least 1 audio-conference per month.
• The Project Director proposes the agenda of the meetings, monitors the implementation of decisions by each WP (through the WP leaders) and makes sure actions have been undertaken. Interactions with the day-to-day management team (Project Office) are expected to occur regularly on administrative and contractual topics that may need both contributions of the authority, coordinator and PMB.</td></tr>
<tr><th colspan="2">Project coordinator (coordinator)</th></tr>
<tr><td>Activities</td><td>• coordinator (P1, CIMR) is the legal entity acting as the unique intermediary between the partners and the authority. It will, in addition to its responsibilities as a partner, have to perform the tasks assigned to it as described in the Agreement and the consortium Agreement. The coordinator provides all information and submits all documents to the Authority and ensures the liaison between the consortium and the Authority. The coordinator is also responsible for submitting the financial statements, receives all payments from the Authority and distributes them appropriately among the consortium. The Project coordinator is the project director who is responsible for the overall project coordination, including legal, contractual and financial issues.
• Responsible for reporting including the preparation of the final Reports and the Technical Audit.
• Responsible for the procedures to be followed in the Project and documented in the Project Handbook, and for the Project archive.
• Monitor the overall technical progress and quality of results in cooperation with the TM, QM and the WPL.
• Maintain the overall project plan
• Represents the project for external contacts.
• Ensures with RM project risk management</td></tr>
<tr><td>Composition</td><td>• 1 person from CIMR</td></tr>
<tr><th colspan="2">Technical Manager (TM)</th></tr>
<tr><td>Activities</td><td>• TM has the overall project responsibility of the consistence of the technical work, and shall take care that the technical goals of the project are met.
• Ensure the common approach in all work packages on technical directions and solutions by maintaining the overall vision of the project. This work contributes to that the technical objectives of the Project are met. TM shall also identify potential interaction problems between the WPs;
• Prepare proposals for the PMB on technical concepts and system view.
• Prepare technical summaries for the Final Report and for the Technical Audit</td></tr>
</table>

	• Give technical presentations both internally and externally.
composition	• 1 person from acp-IT
Quality Manager (QM)	
Activities	• Ensures quality management • Propose quality control plan, make quality control and give solutions and programs for improvements
composition	• 1 person from acp-IT
Risk Manager (RM)	
Activities	• Ensure together with coordinator Risk management • Propose risk control plan, make risk control and give solutions and programs for improvements
composition	• 1 person from CIMR
Project Office (PO)	
Activities	• Will provide all management levels with homogeneous tools and support. A main objective of the PO is to provide a high degree of availability for the other partners, and thus to ease the day-to-day management of the project. Some of its tasks: • Support the Project coordinator and Quality Manager in consolidating and maintaining the quality management plan and the complete time schedule. • Support the Project coordinator and Risk Manager in consolidating and maintaining the risks management plan and the complete time schedule • Preparation of the PMB management meetings. Support during amendments to the contract. • Keep records of the distribution of funds. Monitor the partners' efforts and expenses. Inform immediately the coordinator on any identified deviations according to the financial plan. • consolidation of the official reports. • Support the coordinator in developing and maintaining the adequate project information management framework, using adequate tools. • Develop and maintain the information flow internal and external to the project (contact lists, mailing lists, authorizations, etc.).
composition	• 1 person from CIMR will chair the PO, to enable an optimal cooperation at different levels of management.

Operational level

Project work is divided into Work packages each of them consisting of several tasks / activities. WPL report to coordinator and are in charge of work packages management, while TL report to WPL and are in charge of tasks management.

The nominated WP-Leaders (WPL) must keep track of the progress in work package they are responsible for, regarding the defined tasks and expected results. The WPL are responsible for the reporting on the specific task(s) of the work package, based on templates according to Authority's requirements, and with a summary overview for the coordinator to integrate the scientific and other relevant issues to the appropriate section of the progress reports. WP meetings may be organized as necessary. WP-Leaders have to inform the Project Director if problems are encountered.

Operational Management Team (OMT)	
Activities	• Prepare the Activity Plan; Distribute the tasks to appropriate partners • Build communication channels between tasks within WP and across tasks for a smoother and efficient technical work progress in the project • Keep control of project plans in terms of schedules of deliverables • Responsible for editing the deliverables

	• Risk analysis
composition	• Chairman: TM • Members: WPL and TL
Organisation	• Meetings: four meetings per year, complemented by audio-conference as and when required • TM proposes the agenda of the meetings, monitors the activities of each WP and makes sure actions have been undertaken. • Find solutions for any contingency plans against identified risks.
Work Package Leader (WPL)	
Activities	• WPL is responsible for planning, coordinating and monitoring the work in the associated work package. • The WPL runs also the quality control and risk management together with QM and RM activities at the WP level. • Propose a detailed work plan for the WP. • coordinate and monitor the technical work of the WP, and ensure that it is always aligned with the overall Project Plan. • Plan, schedule and approve the Deliverables, and runs internal WP review process. • Carry out the WP level reporting and provide the WP contribution to the Reports and Audit • Organize the WP level meetings (up to 4 times a year) and ensure that information is exchanged within the WP and with other WP's;
composition	• 1 person per WP from a specific partner
Task Leader (TL)	
Activities	• It replicates WPL activities at task/activity level
composition	• 1 person per WP from a specific partner

Implementation of project management

The project management will be implemented by two sets of means: Administrative and financial coordination activities, and technical management tools. The project director will be in charge of both, being assisted by PBM (especially for technical management).

Next table shows the stated activities and tools to implement the project management.

Administrative and Financial coordination	
Official communication	Either legal (update of contract) or technical (Quality Assurance Plan, management tools, implementation plans).
Meetings	Project Kick-Off meeting, main technical meetings, project reviews, etc. Requires and organize the meetings, follow up of participation lists.
Financial follow up	Transfer of money, budget table, banking information.
Reporting	Due dates notification, collection of WP contribution, reports submission.
Technical Management	
collaborative platform	Used to host the entire project components; users interface, partners zone, management zone, deliverables and reports zone, working zone, demonstrator, testing zone and methods, optimisation and simulation tools, and project "life cycle".
GANTT charts	Used to monitor timing of WPs & tasks. It will track delays in the work and help ensure that the project objectives are achieved within the project timeframe.
Deliverables table	Used to evaluate progress. Deliverables refer to the results to be provided within a WP.
Quality Action Plan and Project	Intended to check partner interaction during the work execution; to check work regularly; detailing how and when documentation must be ex-

Handbook	changed by partners, setting out editorial standards for project contents. Update of the quality assurance procedures, if necessary.
Risk register	It will be set up at the beginning of the project and updated during milestones reviews to implement preventive/corrective actions.

Coordinator's monitoring and reporting progress
The Coordinator elaborates quarterly Reports, final Reports, and the Technical Audit. They provide a comprehensive overview of the project status, single WP objectives, achievements and deviations. The technical part of progress reports will be structured according to the tasks, with specific input from responsible WP-Leaders. List of obtained status of deliverables and milestones, according to the work-packages, will allow a comparison to description of work and thus bring clearness to actual situation. The annual reports will also include a section on the financial status of the project, including cost statements of all partners, audit certifications (if needed) and distribution of Authority's contribution.
Methods for information flow and coherence
Regular meetings will ensure the information flow between the coordinator and the WP leaders regarding their respective duties. Furthermore, regular progress information will be obtained from the partners through their submission of a status reports (max. 1 page) "Work Progress Information Form".
Quality assurance
A part of technical coordination is dedicated to quality assurance and management with its initial step focusing on the definition of quality standards. The quality assurance process will include a set of procedures and actions to be taken on a periodically way to check all project deliverables, i.e., results which will be the project outcomes. The quality checking and cross-reading is a process that helps the PO to release the deliverable. If necessary, the deliverable will be sent back for improvements or postponed for further corrections, if the errors found are major ones.

4.2 WORK PLAN, DELIVERABLES AND LOAD BALANCING

WORK PACKAGE LIST

Work package No[1]	Work package title	Work package leader[2]	Person/month[3]	Start month[4]	End month[5]
1	Project management and co-ordination	P1	3.5	1	24
2	Development of the semi-heterarchical control model for agile and robust manufacturing	P1	38.5	1	7

1 Work package number: WP 1 – WP n.
2 Number of the partner leading the work in the WP
3 The total number of person-months allocated to each work package.
4 Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.
5 Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

3	Creating the job-shop simulation framework and software implementation	P2	20.25	2	9
4	Design and software implementation of the centralized Manufacturing Execution System (MES) with mixed Planning and Scheduling System (SS)	P2	36.75	3	16
5	Designing and implementing the generic distributed MES (dMES) with product-driven automation capabilities	P1	65.75	4	20
6	Testing and validation of the pilot semi-heterarchical MES on an experimental flexible manufacturing cell (FMCell)	P1	45	16	24
7	Dissemination of results	P1	20.75	1	24
	TOTAL				

Using the table below, indicate the description for each work package, specifying the technical and scientific milestones, the bottlenecks or contingencies that could jeopardize the project outcome, and the planned project meetings.

LIST OF DELIVERABLES

Del. no. [6]	Deliverable name	WP no.	WP leader	Nature of deliverable[7]	Dissemination level [8]	Delivery date[9]
1	D1.1 Kick-off meeting report	1	P1	IS	P1	1
2	D1.2 Reports of periodic partner meetings and phase reports	1	P1	IS	P1, P2	8, 16, 24
3	D1.3 Final report	1	P1	IS	P1, P2	24
4	D2.1 The functional specification: operat-	2	P1	IS	P2	2

6 Deliverable numbers in order of delivery dates: D1 – Dn

7 Please indicate the nature of the deliverable using one of the following P1des:
EM = Experimental Model**; FM=** Functional Model**; P** = Prototype, **D** = Demonstrator/ Demonstrative model, **IT** = Innovative Technology, **IS** = Innovative Services.

8 Please indicate the dissemination level using one of the following P1des:
PU = Public
PP = Restricted to other programme participants (including the P1ntracting Authority)
RE = Restricted to a group specified by the P1nsortium (including the P1ntracting Authority)
P1 = P1nfidential, only for members of the P1nsortium (including the P1ntracting Authority)

9 Month in which the deliverables will be available. Month 1 marking the start date of the project, and all delivery dates being relative to this start date.

	ing modes and behaviours, configuring characteristics, functions, performances and evaluation metrics of the connected MES - shop-floor.					
5	D2.2 The model of the semi-heterarchical Manufacturing Execution Control System.	2	P1	IT	P1	6
6	D2.3 Specification of holons (classes, functions, attributes, properties) and holarchy for MES instantiation. Multi-agent framework for basic holons (product, order, resource) and service holons (supply, WIP) instantiation. Staff holon (SH) specification and implementing model.	2	P1	IT	P1	4
7	D2.4 The resource management model and its multi-agent framework for resource team configuration. complete specification of the Resource Service Access Model (RSAM) and instantiation through the resource broker agent.	2	P1	IT	P1	6
8	D2.5 Algorithms and computational model of the centralized scheduling system (SS) for mixed batch planning and product scheduling.	2	P1	IS	P1	8
9	D2.6 Framework for collaboration between the Scheduling System (SS) and the distributed MES (dMES). Models for: management of rush orders, resource breakdown, early maintenance and performance degradation. communication protocols and SS-dMES data exchange specification.	2	P1	IT	P1	6
10	D3.1 Complete model specification for the manufacturing equipment (materials, resources).	3	P2	IS	P2	3
11	D3.2 Set of simulation models for all types of shop-floor devices and activity flows, subject to geometric and operating constraints.	3	P2	IT	P2	5
12	D3.3 Data exchange specification and models of the interfaces connecting shop-floor devices to the MES.	3	P2	IS	P2	5
13	D3.4 Simulation model of shop-floor equipment connected to the MES.	3	P2	IT	P2	8
14	D3.5 Simulation model of the virtual production system: manufacturing team equipment controlled by the MES, executing batch production.	3	P2	FM	P1	8

15	D3.6 Technical documentation of the simulation platform for production execution under MES control. User guide of the testbed modelling tool with application examples.	3	P2	IS	P2	8
16	D4.1 The generic set of engineering data containing information about physical entities (products, operations, supply parts, production orders, processing resources and transport routes), their properties and flow specification (source, destination, format, timing).	4	P2	IS	P2	4
17	D4.2 The MES software modules and user interfaces for the management and configuration of Customer Orders, Job Specification, Fabrication coordination and Monitoring, Materials and Recipes and Product History.	4	P2	FM	P2	6
18	D4.3 Design methodology and software implementation of the Advanced Planning System for mixed batch planning and product scheduling (the centralized Scheduling System - SS), with the components: Release/Demand Planning, Human Resource Planning, Maintenance Scheduling, Online Scheduling and Dispatching, and Rush Order Management.	4	P2	IT	P2	9
19	D4.4 Fault-tolerant communication interfaces between the centralized MES and the shop floor PLC (for product routing and connectivity with manufacturing resources).	4	P2	IT	P1, P2	11
20	D4.5 Design methodology and multi-agent implementing framework for resource team configuration, with graphical user interface for initial team specification and resource broker agent for event-triggered team reconfiguring. Replication mechanism of the distributed Resource Service Access Model (RSAM) and instantiation through the resource broker agent.	4	P2	IS	P1	8
21	D4.6 Integrated software system for the centralized MES, with interconnection of the Fabrication Coordination and Monitoring module with the SS, RSAM, and PLC product routing subsystems. configuration of the MES application for job-shop structures and applications.	4	P2	FM	P2	15
22	D4.7 Technical documentation of the centralized MES, and user manual for	4	P2	IS	P2	16

	production definition and configuration of the resource teams.					
23	D4.8 Demonstrative Flexible Manufacturing Cell with centralized manufacturing control (MES) and connectivity with external ERP applications and user configuration interfaces for: resource team specification, customer order reception and rush orders insertion.	4	P2	MF	P2	16
24	D5.1 The Intelligent Product model in terms of data set, intelligence attributes, location, aggregating capabilities and product-driven mechanisms put in evidence in conjunction with sensing and actuating devices of the product transportation and routing system.	5	P1	IT	P1	5
25	D5.2 Augmentation modules designed and implemented (hardware and software) as Intelligent Embedded Devices on the product carriers (pallets). The IP components will be implemented as agents in JADE running over generic cross platform Java Virtual Machines (VM).	5	P1	FM	P1	11
26	D5.3 Extended FIPA Contract Net Protocol software system for inter-WIP communication in contract-based negotiation and decision taking.	5	P1	IT	P1	11
27	D5.4 Hardware solution, design and implementation of the smart metering subsystem: connecting the smart meters to the monitored resources, connecting the data concentrator (PLC) to the smart meters, linking the PLC to the RSAM.	5	P1	IT	P1,P2	13
28	D5.5 Software system of the resource energy efficiency and service costs model; the system contains a library of power consumption footprints developed as time functions for manufacturing operations and equipment (resources and resource components).	5	P1	FM	P1,P2	13
29	D5.6 Risk and Hazard control system implemented using the supervisory model predictive control (MPC) formulation to ensure uninterrupted process operation at disruptive event occurrence.	5	P1	IT	P2	16
30	D5.7 Methodology and computational model allowing predicting unexpected situations and atypical (unforeseen) situations occurring at disruptive events. Design and implementation of the hu-	5	P1	IT	P2	18

	man-automated interactive decision-making mechanisms for early maintenance of costly resources (significantly exceeding standard power quota) or resources with degraded performances.					
31	D5.8 Demonstrative Flexible Manufacturing Cell with semi-heterarchical manufacturing control, with interconnected SS and dMES subsystems, and scheduling mode commuting control implemented.	5	P1	FM	P1,P2	18
32	D6.1 Complete specification of experimental production scenarios to be realized in variable environment conditions.	6	P1	IS	P2	17
33	D6.2 Technical reports on performed series of experiments, with specification of execution conditions and measured performances.	6	P1	IS	P2	24
34	D6.3 Evaluation of FMCell semi-heterarchical control and predictive maintenance performances, and corrections in the developed software packages.	6	P1	IS	P1,P2	24
35	D6.4 Technical documentation of the functional model of the semi-heterarchical MES.	6	P1	IS	P1,P2	24
36	D7.1 1) 8 scientific papers presented at important international conferences, symposia and workshops in the project's domain / months of delivery: 9, 13, 21, and 24. (2) 4 scientific papers published in prestigious indexed journals with impact factor / months of delivery: 12, and 24.	7	P1	IT	PU	9, 12, 13, 21, 24.
37	D7.2 Information materials (brochures, leaflets, technical sheets) for potential customers, scientific and technical organizations, academia and mass-media	7	P1	IT	PU	14, 19, and 24.
38	D7.3 Organization of the: (1) Exploratory Workshop "MES Benchmarking" / month of delivery: 18; (2) Technical Day for Industry "Integrated Information and Control Systems for Smarter Enterprise" / month of delivery: 24.	7	P1	IT	PU	18, 24
39	D7.4 3 patents (technical documentation submitted)	7	P1	IT	P1,P2	24
40	D7.5 Knowledge and information download about the objectives, outcomes and results obtained in the project	7	P1	IS	PU	8-24
41	D7.6: Website creation and updating: created in month 1, updated until month 24.	7	P1	IS	PU	1-24

4.3 COORDINATION AND TASK SCHEDULE

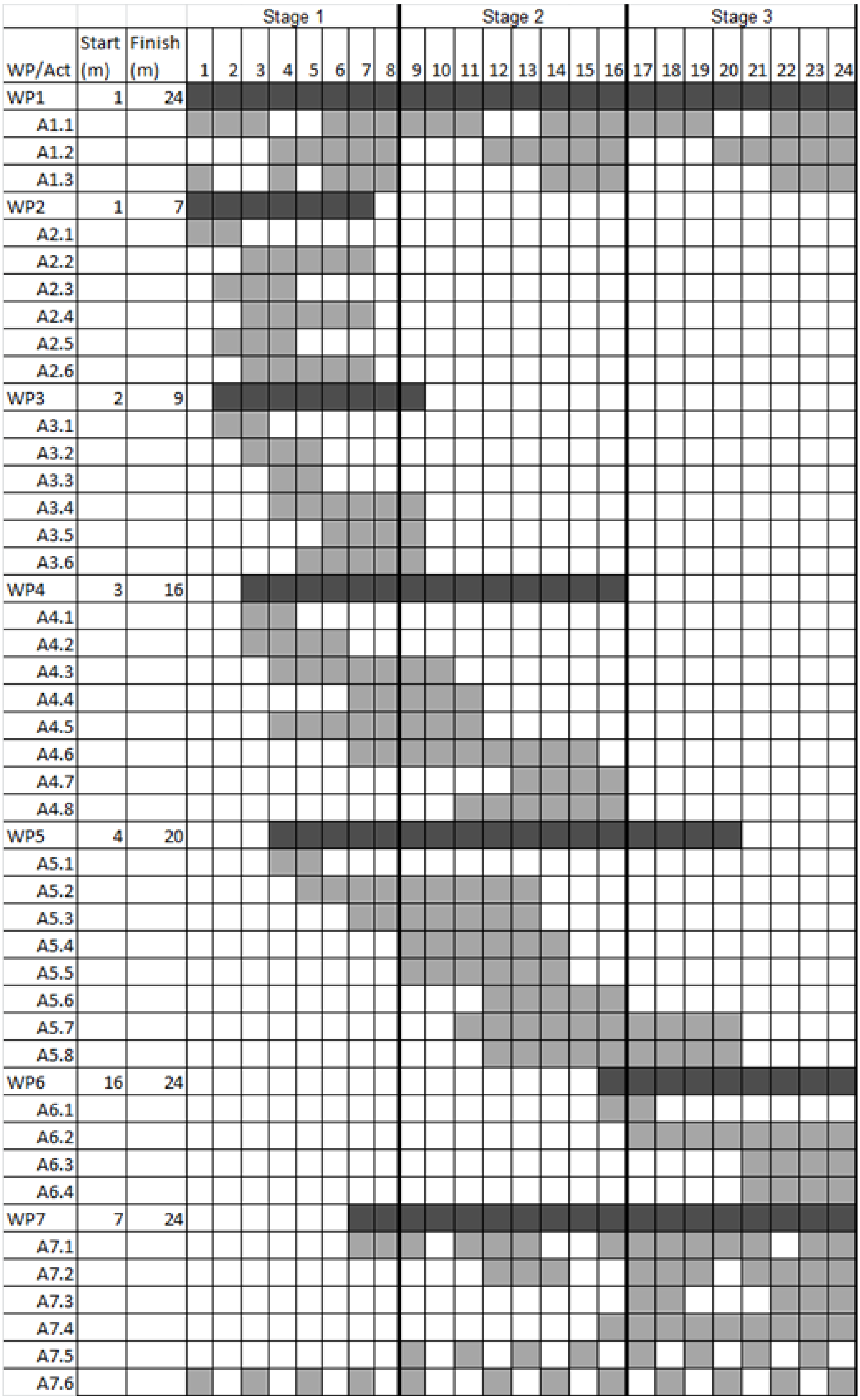

Fig. 5. Gantt chart for activity allocation in time

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